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by Matthew S Tenan, Michael E LaFiandra, and Samson V Ortega

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14. ABSTRACT

Objective: The purpose was to determine if Soldier rucksack load, marching distance, and average heart rate (HR) during shooting affect the probability of hitting the target.
Background: Infantry Soldiers routinely carry heavy rucksack loads and are expected to engage enemy targets should a threat arise.
Method: Twelve male Soldiers performed two 11.8 km marches in forested terrain at 4.3 km/hour on separate days (randomized, counterbalanced design). The Rifleman load consisted of protective armor (26.1 kg); the Rucksack load included the Rifleman load plus a weighted rucksack (48.5 kg). Soldiers performed a live-fire shooting task (48 targets) prior to the march, in the middle of the march, and at the end of the march. HR was collected during the shooting task. Data were assessed with multilevel logistic regression controlling for the multiple observations on each subject and shooting target distance. Predicted probabilities for hitting the target were calculated.
Results: There was a three-way interaction effect between rucksack load, average HR, and march (p = .02). Graphical assessment of predicted probabilities indicated that regardless of load, marching increases shooting performance. Increases in shooting HR after marching result in lower probability of hitting the target, and rucksack load has inconsistent effects on marksmanship.
Conclusion: Early evidence suggests that rucksack load and marching may not uniformly decrease marksmanship but that an inverted-U phenomenon may govern changes in marksmanship.
Application: The effects of load and marching on marksmanship are not linear; the abilities of Soldiers should be continuously monitored to understand their capabilities in a given scenario.

15. SUBJECT TERMS

shooting, heart rate, rucksack, Soldier, shooting, heart rate, inverted-U, military

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The Effect of Soldier Marching, Rucksack Load, and Heart Rate on Marksmanship

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INTRODUCTION

Infantry Soldiers routinely carry heavy loads on the battlefield and need to be able to effectively engage enemy combatants should threats arise. Understanding the impact of Soldier workload on ability to perform a task such as shooting is a matter of survival. Numerous studies have explored the effect of exercise on overall military shooting performance, also called marksmanship (Ito, Sharp, Johnson, Merullo, & Mello, 2000; Knapik et al., 1991, 1997; Nibbeling, Oudejans, Ubink, & Daanen, 2014; Tharion, Hoyt, Marlowe, & Cymerman, 1992; Tharion, Montain, O'Brien, Shippee, & Hoban, 1997; Tikuisis, 2006); however, previous work has indicated that Soldier work may increase (Nibbeling et al., 2014), decrease (Ito et al., 2000; Knapik et al., 1991, 1997; Tharion et al., 1992, 1997), or have no effect (Tikuisis, 2006) on marksmanship. The discrepancy in the literature may be due to methodology; the simulation of military work with treadmill/track exercise (loaded or unloaded) (Ito et al., 2000; Nibbeling et al., 2014; Tikuisis, 2006) or the simulation of marksmanship with paintball munitions (Nibbeling et al., 2014) or laser weapons (Frykman, Merullo, Banderet, Gregorczyk, & Hasselquist, 2012; Ito et al., 2000; Tharion et al., 1992, 1997; Tikuisis, 2006) may not completely replicate live-fire shooting and marching in the field. Furthermore, shooting research in Olympic shooting sports has demonstrated that marksmanship is a complex task that can be modified by both physiological and psychological processes (Helin, Sihvonen, & Hänninen, 1987; Hoffman, Gilson, Westenburg, & Spencer, 1992; Konttinen & Lyytinen, 1992; Konttinen, Lyytinen, & Viitasalo, 1998; Lakie, 2010; Tremayne & Barry, 2001; Vickers & Williams, 2007).

Early work in elite rifle and pistol shooters demonstrated that high-level shooters have lower heart rates (HR) and tend to shoot during diastole (Helin et al., 1987) compared to less

experienced shooters. The deceleration in HR just prior to trigger pull is characteristic of better marksmanship in both novices and expert shooters (Konttinen & Lyytinen, 1992), though the HR deceleration in experts may be more pronounced (Tremayne & Barry, 2001). The Olympic biathlon is a commonly examined sport that requires both exercise at high intensities and precision marksmanship. Increases in HR due to exercise appear to differentially affect shooting in the standing and prone positions (Hoffman et al., 1992), both of which are shooting positions in the biathlon. Standing accuracy, or where a shot hits a target, is substantially decreased with increases in HR, while accuracy only decreases in prone shooting near peak HR (Hoffman et al., 1992). Preliminary evidence in biathletes also suggests that low intensity exercise, with commensurate increases in HR, may initially augment shooting performance before a decline is observed, though there is considerable intra-individual variability that may be due to psychological factors (Vickers & Williams, 2007). Similar to the military research, testing marksmanship with simulated weapons may affect the applicability of the research to actual sport or military environments (Helin et al., 1987; Konttinen & Lyytinen, 1992; Vickers & Williams, 2007).

In addition to the applicability of lab-based methods to in-field marksmanship, previous studies have examined their accuracy data as number of target hits (hit percentage) and/or examining the deviations from target center when the target is hit. While knowing a change in hit percentage or the root mean square from the center of the target is valuable, it is more meaningful in both the military and sport domains to know the probability that each individual shot will hit the target as opposed to a group of shots. Similarly, examining the hits in deviation from target center truncates valuable information. For instance, knowing that a certain condition results in accuracy deviations only toward the lower right region of the target is more informative than simply knowing that the target hits are further from the center of the target. Therefore, the goal of the present investigation is to examine the effect of average HR during shooting, load carriage, and military

TABLE 1: Participant Demographics

Demographic	Mean	Range
Mass (kg)	80.7	67.8–99.3
Height (cm)	176.5	166.3–189.4
Age (years)	23.7	20–33
Years of military service	4.4	1–15

marching on the probability of hitting the target and accuracy of target hits. Specifically, we hypothesize that lower heart rates will increase marksmanship and that this effect will be uniform across all time points. Furthermore, an increase in overall work, both by increasing the mass carried and increased length of march, will decrease overall marksmanship.

METHOD

Participants and Informed Consent

A sample of 12 male Soldiers from the 101st Airborne Division (Air Assault) participated in the study (Table 1). All Soldiers had previously qualified as either a Sharpshooter or Expert with an M4 carbine and carried heavy rucksack loads as normal professional activity. Expert and Sharpshooter are the first and second, respectively, levels of qualification out of four levels in the United States Army. All Soldiers had at least 20/30 corrected vision as assessed with the Titmus Vision Screening device and were cleared for normal duties without medical accommodations. This research complied with the Declaration of Helsinki and was approved by the U.S. Army Research Laboratory Institutional Review Board. All subjects gave written informed consent prior to participation.

Equipment and Facilities

Soldier HR and march speed were continually monitored with a Garmin Forerunner 110 and chest strap sensor. The shooting task was completed with a standard issue M4 carbine with the M68 Close Combat Optic, which was zeroed by the Soldier on the first familiarization day. The Rifleman load totaled 26.1 kg and included the full Soldier uniform (clothes, boots, combat helmet, etc.), protective body armor, decommissioned M4 carbine, simulated

munitions, and a quart of water. The Rucksack condition included the materials from the Rifleman load as well as a weighted rucksack, bringing the total load to 48.5 kg. The weighted rucksack was "inert" in that the weight was evenly distributed throughout the pack with a weight that occupied the entire rucksack uniformly.

The cross-country course is a path through a heavily wooded area. The path is unobstructed in places but elsewhere crosses marshes, thick foliage, fallen trees, and brush. The total length of the cross-country course is 4.3 km with minimal elevation change. The distance from the end of the cross-country course to the shooting range is 1.6 km. For the purposes of the present study, the cross-country course distance and the distance from course end to shooting range equate to half of the overall march, and the course was repeated twice for a total net distance of 11.8 km for each testing session.

The live-fire shooting range consists of parallel firing lanes with target positions at both 100 and 150 meters. Target presentation is automated and controlled with customized algorithms, enabling the operator to modify presentation and retraction. In the present study, targets were exposed individually for 8 seconds, with presentation separated by 2.5 seconds, for a total of 48 targets. The targets were olive drab green, with a white 2×2 inch square placed in the center for Soldiers to use as an aim point. A shot is recorded by microphones placed at the shooter's position and the target. The shot generates a shock wave detected by the microphones and is used to triangulate the shot location, accurate within 5 millimeters, expressed as Cartesian coordinates on the target. While the system is able to accurately determine shot accuracy, the individual measurements are unable to be directly tracked back to the shot taken when a series of shots are taken within a scenario, as done in the present study.

Pretesting Familiarization

To ensure the Soldiers were comfortable with the study set-up and to limit learning effects, two days of familiarization were performed prior to the two days of testing. On the first familiarization day, the Soldier carried the Rifleman load and performed half of the testing protocol (5.9 km march and shooting). On the second familiarization day, the Soldier carried a lighter rucksack load than during the testing protocol, totaling 39.7 kg, and performed half of the testing protocol march.

Testing Protocol

The experimental trials were performed two days following the familiarization. The loads used within the experiment were counterbalanced and randomly assigned. Each testing day was the same with the exception of the load carried. All testing was performed during clear weather conditions, in the morning from late May to early June at Aberdeen Proving Ground, Maryland. The start time was standardized within each subject.

Prior to the march, the Soldier performed a pre-march shooting scenario. In all shooting scenarios, there were 48 targets, exposed for 8 seconds, where they were given verbal instructions prior to each shot to assume either a standing, kneeling, or prone posture. The postural changes were an attempt to eliminate posture-specific effects of fatigue and HR on marksmanship (Hoffman et al., 1992). The Soldier was instructed to aim for the center of the target and only shoot once per target. All shooting scenarios were performed wearing the Rifleman load only. When the Soldier was carrying the Rucksack load, he would release the rucksack immediately and enter the shooting scenario without delay. The rucksack was released prior to shooting because this is a standard tactic employed when engaging an enemy on the battlefield. Average HR during shooting was logged electronically and stored for offline analysis. After performing the pre-march shooting scenario, the Soldier was transported via vehicle to the start of the cross-country course.

The Soldier marched on the cross-country course at a speed of 4.3 km/hour; therefore, speed of course completion was uniform between and within Soldiers. The speed and HR were continually monitored by research staff who traveled with the Soldier and set the pace during the march. Water was consumed ad libitum. At the end of the first cross-country march, the Soldier's HR rate was noted. The Soldiers adjusted their walking speed so that this HR was maintained as the Soldier completed the 1.6 km

march on a flat, grassy path to the shooting range; standardizing workload to HR, instead of speed, was used during this portion of the march because pilot testing indicated that the terrain in this section of the march resulted in a substantially lower HR than during the forested terrain. Upon reaching the shooting range, the Soldiers would release the rucksack (if wearing one) and exchange their dummy M4 for the M4 carbine they zeroed during the familiarization period. The Soldier then entered the shooting scenario as previously described. Upon completing the mid-march shooting scenario, the Soldier was transported via vehicle back to the start of the cross-country course. The second half of the march and the end of march shooting scenario had the same form as described previously.

One Soldier was unable to complete the march with Rucksack load due to an ankle injury sustained on the cross-country march, and partial data from his Rucksack visit was not included in the analysis.

Statistical Analysis

All statistical analysis was performed in SAS 9.4 (Cary, North Carolina, USA). All figures were created in R (R Core Team, 2014), using the dplyr (Wickham & Francois, 2015) and ggplot2 (Wickham, 2015) packages. Repeated measures t tests were performed to examine the effect of rucksack load on heart rate at the completion of the cross-country course for mid-march and end of march to confirm that carrying heavier loads results in physiologic changes. A multilevel logistic regression controlling for the multiple observations (shots) from each participant and the distance of the target was used to assess the odds of the Soldier hitting the target with average HR during shooting, rucksack load, and the shooting trial as predictors. Specifically, the maximum likelihood estimation technique was utilized with the Laplace likelihood approximation. The multiple observations were controlled for with a subject-level random effect using the unstructured Cholesky root variance/covariance structure. The target distance, as a categorical variable, was controlled via an ANCOVA methodology, and all result estimates were standardized to a 150 meter shooting distance. Significance level of logistic regression

estimates was set at $\alpha = 0.05$. The multilevel logistic model was assessed for predictor multicollinearity, and it was found that the information matrix was unbiased. Based on logistic regression model estimates, predicted probabilities are calculated for the load and trial at various HRs. The accuracy of the target hits was plotted, and the dispersion was assessed visually with a two-dimensional kernel density estimation plot.

RESULTS

The last HR recorded for both mid-march and at the end of the march was elevated in the rucksack load condition (mid-march: 151.5 bpm vs. 136.1 bpm; $t[10] = 6.00$, $p < .001$; end of march: 159.6 bpm vs. 136.5 bpm; $t[9] = 3.32$, $p = .001$).

Per the shooting protocol, a total of 3,312 target presentations were made. The study recorded 3,045 shots, indicating that 267 shots were withheld because the Soldier was unable to fire his weapon before the target was removed from view. The count of withheld shots was generally uniform across participants and load trial, but there were 139 withheld shots at pre-march, 39 withheld shots at mid-march, and 43 withheld shots at march completion. Of the shots recorded, 1,985 hit the target, and 1,060 missed.

The full parameterized logistic regression for target hit/miss was significantly better fitting than the null model, $\chi^2(26) = 181$, $p < 0.01$, and indicated multiple significant effects (Table 2). Most importantly, the three-way interaction between rucksack load, average HR, and march point was significant ($p = .02$). The point estimates from the logistic regression were used to calculate the predicted probability of hitting the target for each march point and load across a range of HRs (Figures 1–3). The visual representation of the predicted probability of hitting the target is the most informative way to interpret a three-way interaction in a multilevel logistic regression.

The accuracy of target hits was overlaid on the target silhouette and plotted with a two-dimensional kernel density estimation. There was no clear change in accuracy or shot grouping in either Rifleman (Figure 4) or rucksack load (Figure 5). In each condition, the hits appear to be centralized at the center of the target.

TABLE 2: Omnibus Tests for Significance in the Multilevel Logistic Regression Model

Effect	Degrees of Freedom	F Statistic	p Value
Load	(1, 3021)	0.23	.63
Average heart rate (HR)	(1, 3021)	2.07	.15
March point	(2, 3021)	6.23	<.01
Load × March Point	(2, 3021)	3.25	.04
March Point × Average HR	(2, 3021)	4.87	<.01
Average HR × Load	(1, 3021)	0.01	.91
Load × Average HR × March Point	(2, 3021)	4.87	.02
Distance	(1, 3021)	144.43	<.01
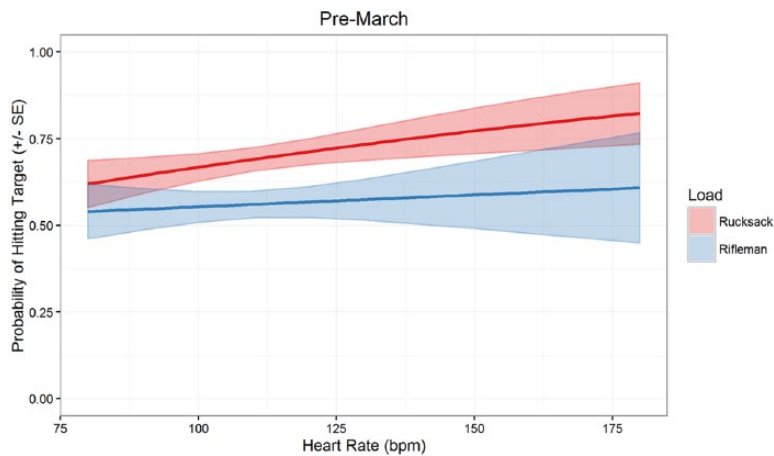
Figure 1. Predicted probability (±*SE*) of hitting the target by average heart rate at pre-march for each of the loads.

DISCUSSION

Previous research has suggested that there is a linear effect of increases in Soldier physical load and decreases in marksmanship (Ito et al., 2000; Knapik et al., 1991, 1997; Tharion et al., 1992, 1997). The present study, which examines marksmanship ability at multiple time points, suggests that marksmanship is a multifaceted task that can be both augmented or decremented by various factors. The effects of load and average shooting HR on marksmanship are nonlinear when examining hit/miss attributes of marksmanship, but when a target is hit, the accuracy is not modified.

The Effect of "Load"

An incidental but surprising finding from the present study was that pre-march marksmanship performance was increased by 10% to 20% in the rucksack load condition. This finding is especially surprising considering that no load had been carried at that point, and the Soldier was simply notified that they would be carrying the load at a later point in the visit. The increase in performance may be viewed in the context of the Yerkes-Dodson arousal-performance curve (Robert & John, 1908). In the context of the pre-march data, the Yerkes-Dodson law would state that knowledge that the heavier rucksack load would be carried later in the task increased their levels of arousal, causing an increase in performance. The suggestion that psychological arousal accounts for the phenomena observed is conjecture since no psychological testing was performed as a part of the current study. Future studies from our research group are exploring the nature of this phenomenon, theoretical
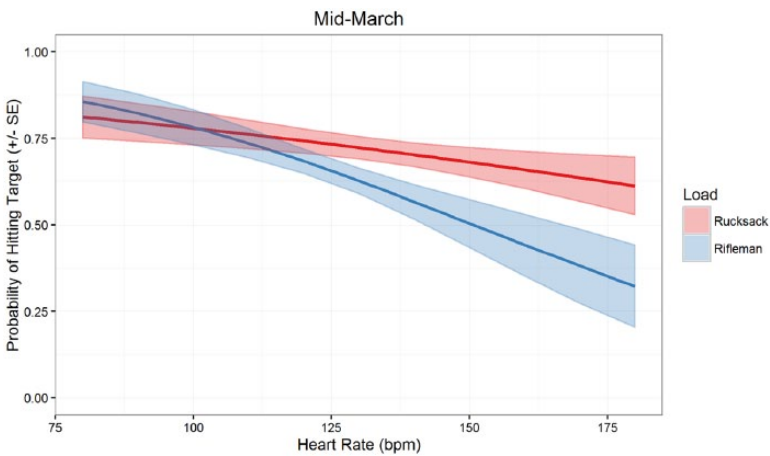
Figure 2. Predicted probability (±*SE*) of hitting the target by average heart rate at march midpoint for each of the loads.
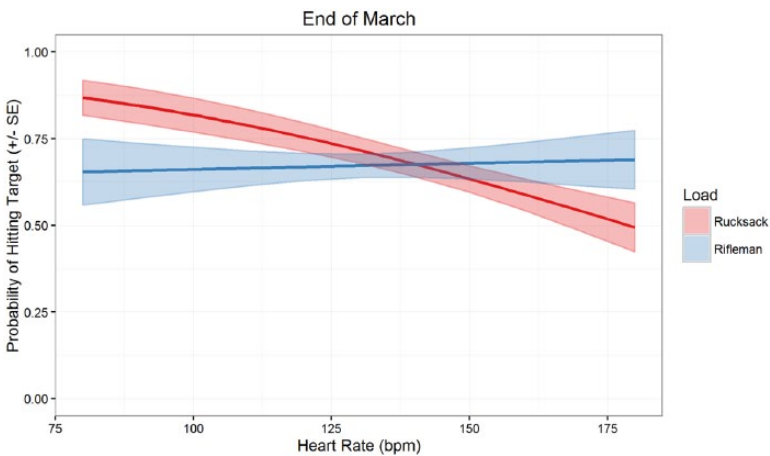

Figure 3. Predicted probability (±*SE*) of hitting the target by average heart rate at the end of the march for each of the loads.

explanations, and implications for Soldier performance in the field.

Exercise and Marksmanship

Previous work has suggested that exercise fatigue is a substantial physiologic factor that decreases marksmanship performance (Ito et al., 2000; Knapik et al., 1991, 1997; Tharion et al., 1992, 1997). Research has also suggested that increases in HR cause a mechanical alteration in shooting trajectory, resulting in decreased performance (Helin et al., 1987; Tremayne & Barry, 2001). The present study indicates that both of these claims are an overly simplistic representation of real-world Soldier marksmanship dynamics.

Fatigue is a multifactorial, nonlinear, and dynamic process that encompasses both physiologic and psychologic processes and their interactions (Gibson & Noakes, 2004). The present study applied two different physical loads to the Soldier and hypothesized that the rucksack load would cause fatigue, decreasing marksmanship at mid-march that becomes worse at march completion. Instead, there was no clear effect of the increased rucksack load on marksmanship at
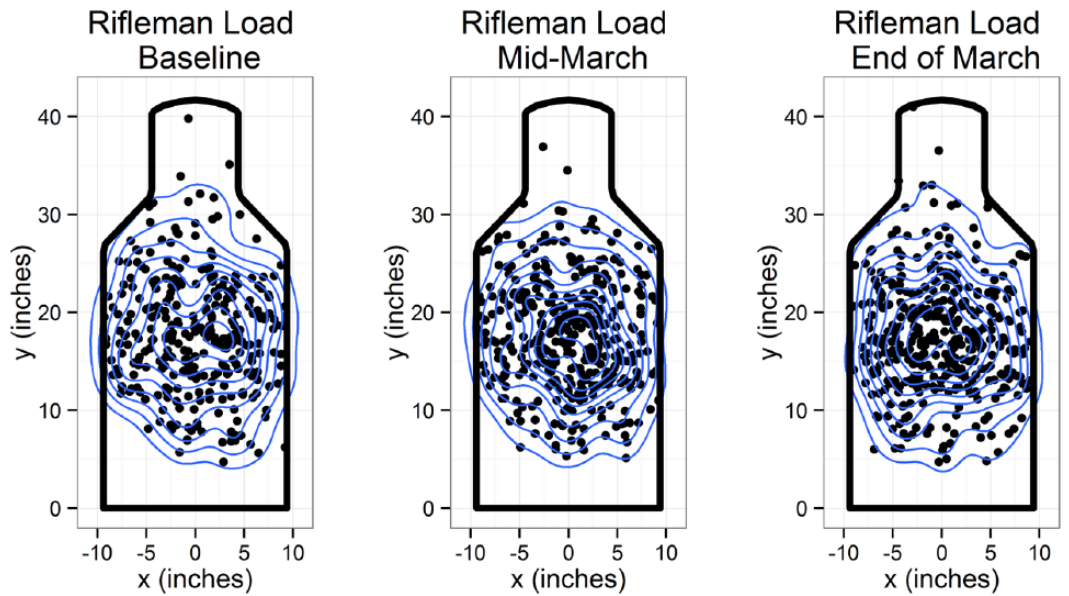
Figure 4. The individual coordinates for each shot that hit the target during the Rifleman load condition are plotted with a two-dimensional kernel density plot where higher densities are contained within lower densities.
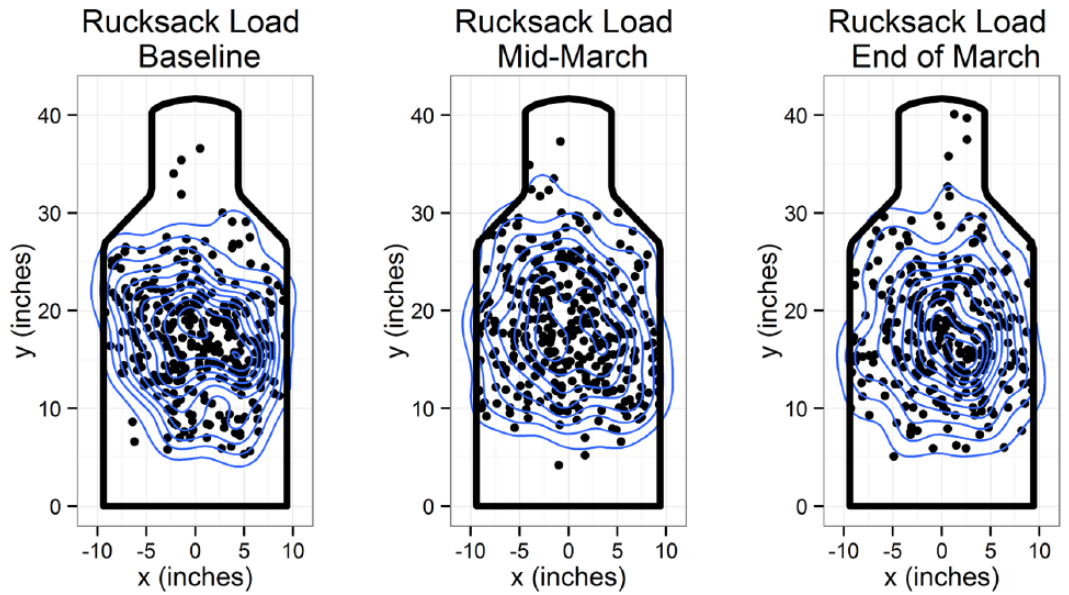

Figure 5. The individual coordinates for each shot that hit the target during the rucksack load condition are plotted with a two-dimensional kernel density plot where higher densities are contained within lower densities.

either mid-march or completion. Regardless of physical load, marching actually increased marksmanship compared to pre-march at low and moderate HR. The increased marksmanship performance in the present study stands in stark contrast to previous work on Soldiers, which shows a definite decrease in shooting performance after marching (Knapik et al., 1991, 1997). However, one of those studies indicates that 15% of their subjects sought medical attention either

during or after the march (Knapik et al., 1991), suggesting that their 20 km marching protocol was substantially more difficult than the one used in the present study. The works by Knapik et al. (1991, 1997) used a longer road march than the present study (20 km vs. 11.8 km) but also had Soldiers march at a variable self-selected pace that met the goal of "completing the course as rapidly as possible." In contrast, the present study maintained a constant speed for the majority of the march, which may be more militarily relevant as Soldiers are often required to march in groups at a consistent pace. That the physical load carried had minimal effect on marksmanship but marching causes both an increase (present study) and decrease (Knapik et al., 1991, 1997) in marksmanship depending on march length suggests that total distance traveled is the strongest contributing factor for marksmanship alteration.

In the context of the present study, the differential effects of HR as a measure of physiologic exertion and mechanical perturbation are difficult to untangle. Increases in HR may slightly increase marksmanship prior to marching but appear to substantially decrease the probability of hitting the target after marching. This decrease in probability may be due to the increased mechanical effects of the heart beat on shooting dynamics or represent an "over-arousal" and resulting decrease in performance according to the Yerkes-Dodson curve. Future studies should investigate the interaction of these mechanical, physiological, and psychological effects in marksmanship with greater nuance to understand the dynamic interplay of these factors on marksmanship.

Application of Study Findings

The present study has implications for the military as well as the Olympic biathlon and shooting. The psychological aspects of shooting at rest should not be discounted. There may be sport-specific strategies that can be employed that will raise the arousal level of Olympic shooters without increasing mechanical effects of increased HR and result in a 10% to 20% increased probability of hitting the desired target. In the context of exercise, marksmanship training should continue focusing on increasing rapid

parasympathetic control. Some of this rapid decrease in HR after ceasing exercise is a natural product of increasing fitness (Carter, Banister, & Blaber, 2003), but there may be other methods of biofeedback or neurocognitive training that can augment parasympathetic control to increase marksmanship. Since a combination of HR and exercise distance or duration appears to be a strong factor in marksmanship, it is possible that biathlon racing strategies such as slowing down prior to shooting should be modified depending on point in the race. In a military context, an effort should be made to limit the duration and distance of military marches as opposed to limiting pack weight; however, the present study examines only marksmanship and does not account for other negative outcomes that may befall a Soldier or Olympian such as injury or other fatigue-induced unfavorable outcomes.

The results of the current study do not directly refute the findings of previous lab-based studies; however, it does caution against extrapolating lab metrics into the field without testing. Multiple psychological, physiological, and mechanical factors need to be considered within one model in order to determine which effects are incidental or secondary to more profound elements.

KEY POINTS

- Soldiers are expected to carry heavy loads but need to be able to engage enemy combatants when threats arise.
- Previous work suggests that exercise may increase, decrease, or have no effect on marksmanship.
- Present work suggests that the effect of exercise and workload have nonlinear effects on marksmanship that may follow an inverted-U phenomena.

- Our results provide greater insight into the dynamics of Soldier marksmanship performance and may explain discrepancies in previous literature.

REFERENCES

Carter, J. B., Banister, E. W., & Blaber, A. P. (2003). Effect of endurance exercise on autonomic control of heart rate. *Sports Medicine*, *33*(1), 33–46.

Frykman, P. N., Merullo, D. J., Banderet, L. E., Gregorczyk, K., & Hasselquist, L. (2012). Marksmanship deficits caused by an exhaustive whole-body lifting task with and without torso-borne loads. *Journal of Strength and Conditioning Research*, *26*, S30–S36.

Gibson, A. S. C., & Noakes, T. (2004). Evidence for complex system integration and dynamic neural regulation of skeletal muscle recruitment during exercise in humans. *British Journal of Sports Medicine*, *38*(6), 797–806.

Helin, P., Sihvonen, T., & Hänninen, O. (1987). Timing of the triggering action of shooting in relation to the cardiac cycle. *British Journal of Sports Medicine*, *21*(1), 33–36.

Hoffman, M., Gilson, P., Westenburg, T., & Spencer, W. (1992). Biathlon shooting performance after exercise of different intensities. *International Journal of Sports Medicine*, *13*(3), 270–273.

Ito, M., Sharp, M., Johnson, R., Merullo, D., & Mello, R. (2000, December). *Rifle shooting accuracy during recovery from fatiguing exercise*. Paper presented at the Army Science Conference, Baltimore, MD.

Knapik, J., Ang, P., Meiselman, H., Johnson, W., Kirk, J., Bensel, C., & Hanlon, W. (1997). Soldier performance and strenuous road marching: Influence of load mass and load distribution. *Military Medicine*, *162*(1), 62–67.

Knapik, J., Staab, J., Bahrke, M., Reynolds, K., Vogel, J., & O'Connor, J. (1991). Soldier performance and mood states following a strenuous road march. *Military Medicine*, *156*(4), 197–200.

Konttinen, N., & Lyytinen, H. (1992). Physiology of preparation: Brain slow waves, heart rate, and respiration preceding triggering in rifle shooting. *International Journal of Sports Psychology*, *23*, 110–127.

Konttinen, N., Lyytinen, H., & Viitasalo, J. (1998). Preparatory heart rate patterns in competitive rifle shooting. *Journal of Sport Science*, *16*(3), 235–242.

Lakie, M. (2010). The influence of muscle tremor on shooting performance. *Experimental Physiology*, *95*(3), 441–450.

Nibbeling, N., Oudejans, R. R., Ubink, E. M., & Daanen, H. A. (2014). The effects of anxiety and exercise-induced fatigue on shooting accuracy and cognitive performance in infantry soldiers. *Ergonomics*, *57*(9), 1366–1379.

R Core Team. (2014). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from http://www.R-project.org/

Robert, M. Y., & John, D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology*, *18*, 459–482.

Tharion, W., Hoyt, R., Marlowe, B., & Cymerman, A. (1992). Effects of high altitude and exercise on marksmanship. *Aviation Space and Environmental Medicine*, *63*(2), 114–117.

Tharion, W., Montain, S., O'Brien, C., Shippee, R., & Hoban, J. (1997). Effects of military exercise tasks and a carbohydrate-electrolyte drink on rifle shooting performance in two shooting positions. *International Journal of Industrial Ergonomics*, *19*(1), 31–39.

Tikuisis, P. (2006). *Target detection, identification & marksmanship under various types of physiological strain*. Paper presented at the 25th Army Science Conference, Orlando, FL.

Tremayne, P., & Barry, R. J. (2001). Elite pistol shooters: Physiological patterning of best vs. worst shots. *International Journal of Psychophysiology*, *41*(1), 19–29.

Vickers, J. N., & Williams, A. M. (2007). Performing under pressure: The effects of physiological arousal, cognitive anxiety, and gaze control in biathlon. *Journal of Motor Behavior*, *39*(5), 381–394.

Wickham, H. (2015). *ggplot2: Elegant graphics for data analysis* (Version R package version 0.9.3.1). Retrieved from http://CRAN.R-project.org/package=ggplot2

Wickham, H., & Francois, R. (2015). *dplyr: A grammar of data manipulation* (Version R package version 0.4.1). Retrieved from http://CRAN.R-project.org/package=dplyr

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